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QUANTITATIVE MODELING OF THE RELATIONSHIPS AMONG BASIN, CHANNEL AND HABITAT CHARACTERISTICS FOR CLASSIFICATION AND IMPACT ASSESSMENT

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CMER PROJECT 16D

Prepared for the
AMBIENT MONITORING COMMITTEE
Timber, Fish and Wildlife Program

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QUANTITATIVE MODELING OF THE RELATIONSHIPS AMONG BASIN, CHANNEL AND HABITAT CHARACTERISTICS FOR CLASSIFICATION AND IMPACT ASSESSMENT

INTRODUCTION

Project Summary

This project was undertaken to help the Ambient monitoring Committee (AMC) of the Timber, Fish and Wildlife Program (TFW) develop an integrated, physical, analytical basis for its CLASSIFICATION and MONITORING programs. The heart of the project involves quantitative analyses of the components of a drainage basin system--its hydrologic, basin and stream channel characteristics. These study components include interrelationships among basin morphology, channel morphology, hydrology, streamflow, fisheries habitat and sediment transport.

Analyses of these components are based on interrelating and integrating fundamental principles from the technical fields of:

- geomorphology
- engineering hydrology
- fluid mechanics
- hydraulic engineering
- river engineering
- fisheries requirements
- conceptual modeling
- similitude
- mathematical modeling, and
- systems analysis.

This report is arranged in two major parts covering: (1) a non-technical overview; and (2) a series of technical and non-technical appendices. These appendices describe the methodologies applied and the results developed for use by the AMC, and its cooperators and contractors, in their future work of developing management tools based on classification, monitoring and feedback. The appendices are:

- References
- Nomenclature
- Hydrology and Hydrologic Models
- Drainage Basin Perspectives and Processes
- Stream Channel Characteristics
- Integration of the Water-Basin System Parts
- Application of Hydrologic, Basin and Channel Characteristics to Classification
- Expert Workshop Summary
- Comments on the Monitoring Program

The Ambient Monitoring Committee's Program

The AMC workplan is summarized to provide the project foundation by emphasizing the development of stream classification methods, and the monitoring and the research tasks. These tasks interact to assist in the development of adaptive management and impact analysis procedures. The AMC preliminary classification systems are tabulated and the components of this quantitative modeling project are summarized. The project emphases are on quantitative modeling of the physical aspects of stream channel responses to changes in organic, inorganic and streamflow loads. Sediment is the only water quality parameter given consideration.

The various components of the project, their applications (utility) and their quantifiable parameters are summarized to describe the breadth and depth of the project. The Olympic Peninsula, which is a unique ecoregion with diverse hydrologic provinces, is used as the pilot study region for demonstrating the calibration of hydrologic and channel geometry models for use by the AMC program in other monitoring/research areas throughout the State, and for basin and channel classification. The relationships among basin, streamflow and channel parameters should be developed as baseline information for all of the monitoring/research channel sites. Otherwise there will be no water-supply data base for the monitoring sites, and no connecting link for evaluating causes and effects, or land-use changes and downstream responses.

The Ambient Monitoring Committee (AMC) is developing methods for evaluating the potential impacts of land use activities on downstream channels, riparian areas and fisheries habitats. The AMC activities include: monitoring projects of selected stream sites in various timber regions of the State; the development of specific valley segment classifications for some of those regions; the construction of a conceptual classification system; and the preparation of a program workplan (AMC 1989). The workplan describes the logic for the development of a stream classification system as supported by short-term and long-term stream monitoring and research programs. As more information is developed the classification system and impact analysis procedures will be refined through adaptive management. These two phases of the AMC program are interactive in that the classification system guides the monitoring and research programs. In return, the monitoring and research information feeds back to the classification system for refinement.

Because the AMC coordinates its activities with those of other committees such as Mass Wasting, Hydrology and Sedimentation, Riparian Zones, Temperature and Fisheries, portions of this project report relate to some of the subject areas being examined by these committees. The combined, long-range goal of the AMC tasks is to provide better methods for managers and regulators to decide on the best alternative with respect to the potential interaction among logging and road building activities on a watershed, and impacts on downstream resources such as riparian timber, fish and wildlife (AMC 1989). The functions and logic for these processes are described graphically in Figure 1.

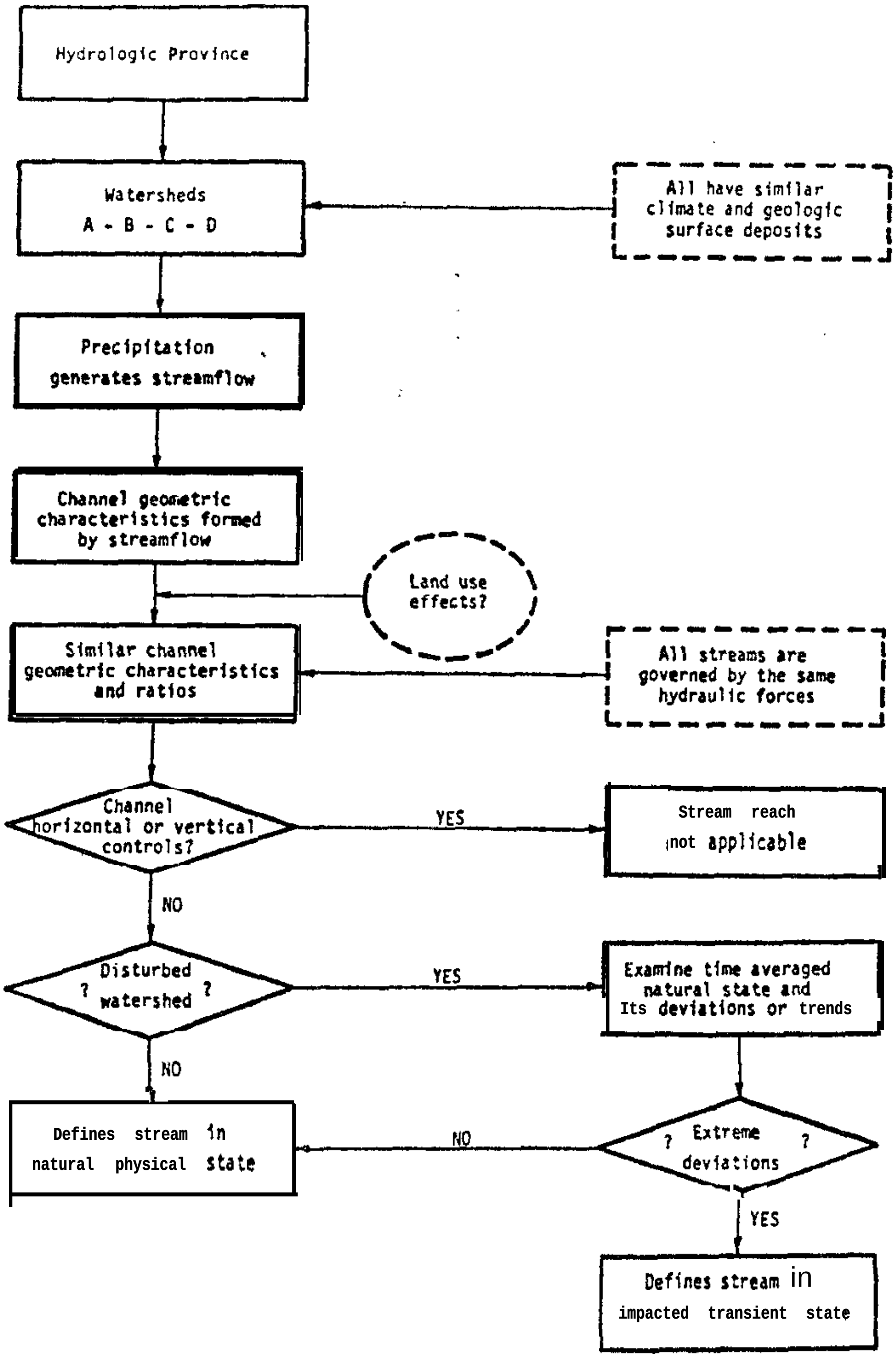

Figure 1. Flow chart of logic to determine the natural or transient state of a stream (Stypula 1986).

Beginning with a particular geographic region (such as the Olympic Peninsula) there are subregions within which the climate is fairly uniform (such as the west coast of the Peninsula). This type of a climatic-geographic region is called a HYDROLOGIC PROVINCE as shown at the top of Figure 1. Precipitation. changes as a function of elevation as do the soils, geology and vegetation (in response to the controls exerted by climate and soils on vegetation). The STREAMFLOW, in response to precipitation, temperature, soils, plants and geology, represents the net result of all these effects on the precipitation. These interrelationships can be arranged in a series of postulates which describe the processes depicted in Figure 1:

- If a watershed receives precipitation and part of the precipitation is released as stream flow through a stream network; and, if the geometric characteristics of the stream network are formed by this stream flow, then there should be physical relationships among the stream network geometric characteristics and the stream flow regime because the network and flow are interdependent parts of the same fluvial morphologic system;

- If a set of watersheds are within a hydrologic province and have similar geologic surface deposits within which the stream networks are formed, then the geometric characteristics of the stream networks should be similar in all watersheds within the subset;

- If the interactions of stream flows and freely deformable stream network boundaries are governed by the same hydraulic forces associated with energy dissipation, shear stresses and momentum, then stream channels of different sizes should have comparable dimensionless geometric ratios;

- If stream channels of different sizes have definite physical, geometric and hydraulic scale ratios, then a set of parameters describing these relationships for undisturbed watersheds should define the natural, physical state of a stream reach, reaches and the network; and

- If the time averaged natural state and its deviations can be defined for a system of stream reaches or networks, then streams which display extreme deviations from the natural hydraulic geometry in a hydrologic province can be considered to be in an impacted, transient state (i.e., anomalies). (Stypula 1986)

Therefore, a principal objective of this study is to develop a physical basis for the interrelationships among the physical characteristics of hydrology, drainage basins, stream channels and stream flow from which the natural or modified state of streams within the same, or other hydrologic provinces (or ecoregions), can be determined. Quantification of the parameters needed to compare those provinces, and streams within the provinces, should provide the basis for classification system(s), and thus guide the monitoring program. A more direct description of the potential changes in natural processes, and in channels, habitat and fish populations, due to logging and road building is displayed in Figure 2.

Project Design

To assist the AMC and other TFW Committees in achieving their goals, the tasks for this project were designed to:

(1) PERFORM A TECHNICAL SYNTHESIS of the TFW ambient monitoring program;

(2) ANALYZE the relevance of methods and variables for STREAM CHANNEL MONITORING AND CLASSIFICATION;

(3) INTEGRATE THE RESULTS OF AN EXPERT WORKSHOP on classification into the synthesis performed in part (1); and

(4) DEVELOP A HYDROLOGIC COMPONENT to augment the synthesis of the ambient monitoring program in part (1).

The technical synthesis of the ambient monitoring program called for inclusion of the following project components:

- Hydrology
- Streamflow conditions
- Sediment
- Channel Morphology
- Habitat features

Integration of the results of the expert workshop into the classification component required consideration of the AMC preliminary classification system as shown in Table 1. Carrying the level of classification down to the consideration of quantifiable physical characteristics leads to the center column in Table 2.

Summarv of the 1989 Preliminarv Project Report

In the preliminary project report of July, 1989 the following topics were discussed to provide an overview of classification methods for consideration by the AMC (Orsborn 1989):

- Summary and commentary on the May, 1989 expert workshop to develop a classification system for evaluating streams and forest practices (Appendix VIII in this report) (Flaherty 1989);

- A systems approach to assessing the condition of streams and their watersheds:

    - the use of basin characteristics to evaluate the condition (state) of streams . . . (Clark 1985) . . . .

    - systems characteristics . . . (Schoderbek 1971) . . . .

LOGGING AND ROAD CONSTRUCTION

PROCESS CHANGES:	Water balance Energy balance Nutrients Sediments
STRUCTURES CHANGES:	Soil structure/stability Vegetation and debris Drainage network Channel shape
DIRECT IMPACTS:	Mass wasting Surface erosion Channel erosion Introduction of organic debris Damage to stream banks/bed Loss of streamside vegetation
HABITAT ELEMENTS CHANGES:	Water velocity/depth Water quality Bed composition Banks Cover type/extent Riparian vegetation Migration barriers
FISH POPULATION CHANGES:	Numbers Species Health Distribution

Figure 2. Relations of logging and road construction to fish (adapted from Chamberlin 1982, by McCrea 1984).

Table 1. Stream Class Strata (persistence column deleted; AMC 1989).

	System Stratification Level		
Classification Level	Class Units (examples)	Physical	Fisheries
Ecoregion	North Cascades Blue Mountains	Regional geology climate, natural'vegetation	Species array
Stream Order/	Orders l-7	Stream size, basin area	Life history stage
Geohydraulic zones	Meandering, step-pool, straight	Valley slope, particle size	Life history stage
Segment	Alluviated valley, incised valley	Hillslope/valley/ stream interaction	Populations (volume of habitat)
Channel Units	Riffles, Pools	Sediment and water in response to bed and bank condi- tions	Individual organism (fish)
Channel units		Same as above	Macroinverte- brates

Table 2. Factors Important in Stream Formation, and Classification Levels Selected to Account for Major Factors (AMC 1989)

Factor	Characteristics	Classification Level
Geology	Basin substrate, dominant sediment delivery process	Ecoregion
Climate	Elevation, precipitation (amount and timing)	Ecoregion
Vegetation type	Ecozones, habitat types	Ecoregion
Watershed size	Discharge (channel* width and depth), drainage area	Stream order/ geohydraulic zone
Valley characteristics	Valley gradient confinement	Segment

*Term added to differentiate channel from watershed width.

- ♦ disturbance and inertial resistance to change . . . .
- ♦ an example of disturbance and response . . . .
- ♦ qualitative features of streams . . . .
- ♦ a set of hierarchical descriptive systems . . . .
- ♦ the stream-segment-unit subsystem (within a drainage basin-stream network) (Orsborn and Anderson 1986, Orsborn and Powers 1985) . . .

■ Modeling of classification systems:

- ♦ classification systems at various levels and for various purposes . . . (AMC 1987, AMC 1989, Frissell 1986) . . .
- ♦ some basic rules . . . (Sokal 1974, Wilson 1984)
- ♦ some examples of scoping the classification system . . . .
  - ◊ the global model (Fisher 1988) . . .
  - ◊ the terrestrial model (Fisher 1988) . . .
  - ◊ the disturbance-response terrestrial model

■ Historical summary of potential classification methods for watershed and stream systems (Terre11 and McConnell 1978):

- ♦ Western U.S. classification systems (Collotzi 1976; Platts 1979, 1980; Rosgen 1985, 1989):
- ♦ historical perspective (Beechie 1988, McCullough 1989, Warren 1979) . . . .
- ♦ an example of a working classification system, and its analysis (Gibbons 1985, Paustian et al. 1983) . . .

■ Consideration of some other classification/evaluation methods for watersheds and their stream systems;

- ♦ river environments (Morisawa 1972, Orsborn 1976) . . .
- ♦ inertia and recovery, a chemical-biological method of stream classification . . . (Stauffer and Hocutt 1980) . . .
- ♦ severity factor analysis (Orsborn and Deane 1976) . . .
- ♦ the land-water (riparian) interface (Karr and Schlosser 1978) . . .
- ♦ examination of other methods of stream and channel classification (Cushing, et al. 1983; Mosley 1987; Schumm

1963) . . . on the basis of the substrate mean grain diameter (Shirazi and Seim 1979)

- Conceptual modeling of a watershed to develop quantitative relationships:

  - regional models of hydrology, channel hydraulics and habitat characteristics of a stream unit . . . (Orsborn 1976) . . .
  - basin characteristics (Amerman and Orsborn 1987, Strahler 1958) . . .
  - channel characteristics (Chang 1988, Hey et al. 1985, Richards 1982)....
  - the allometric approach to modeling fluvial morphology (Osterkamp 1979, Schumm et al. 1987)...
  - hydrologic component of the AMC/TFW program . . .

    - strategy
    - hydrologic input for classification (USGS 1984, USWB 1965) . . .
    - sediment considerations, theory and applications (Begin, et al. 1981; Bhallamudi 1989; Lane 1955; Orsborn, et al. 1985; Soni, et al. 1980; Wesche 1989)

Two appendices were included which provided background information about:

(1) the development of the severity factor method for analyzing the effects of flow changes on fisheries habitat based on channel flow and geometric characteristics (Orsborn and Deane 1976); and

(2) examples of hydrologic models for the Olympic Peninsula pilot study area (Amerman and Orsborn 1987).

Copies of the preliminary 1989 report were provided to designated AMC members. After receiving comments from the AMC members who reviewed the preliminary report, it was decided to shift the emphasis to quantification of hydrologic, basin, channel and fish habitat characteristics. These quantifications would be integrated to provide other means of classifying regions, streams, channels and response variables. These revisions were accomplished in a draft report to the AMC in March, 1990. The AMC requested that the report be rearranged into two parts: (1) a non-technical summary, and (2) a series of technical and non-technical appendices to support and expand the summary. This report is the response to that request. The contents have to be applied and tested, and the methods fine tuned to smaller regions of the State where study and monitoring sites are located.

Project Foundation

In order to consider the comprehensive nature of this project, the quantification of relationships among sediment, hydrology, channel morphology, streamflow conditions and habitat features, one must first expand Tables 1 and 2 into key system components, their sub-components, applications, and quantifiable characteristics of the components. This step has been accomplished in Table 3 which was also a part of the first project report in July, 1989. The parameter column contains the terms for to quantify the classification components in subsequent parts of the report.

A review and summary of Table 3 will prepare the reader for the scope of the project and the interrelated factors which are involved. The key components include:

- ANALYSIS--methodology . . . separation of parts of systems for individual evaluation . . .
- BASINS--as systems and subsystems . . . supplying stream networks . . .
- CHANNELS--natural variability and how they respond to changes in loads . . .
- CLASSIFICATION--for organization of information . . . qualitative and quantitative comparison of basin systems within and among regions . . .
- CLIMATE--general control or regulator of water (and thus plant communities) in conjunction with elevation, geology, soils . . .
- DEFINITIONS--basic form of communication to explain scientific and technical descriptors of components and subcomponents . . .
- ELEVATION--dominant variable affecting air chemistry and precipitation; stream gradient; valley shape: vegetation . . .
- ECOREGIONS--portions of the earth's surface with similar climate, vegetation, geology, etc.... (e.g., hydrologic provinces) . . .
- GEOMORPHOLOGY--science of relating landforms to the forming forces, such as streamflow (fluvial morphology) . . . provides methodology for quantifying regions based on measurements of physical landform features . . .
- HABITAT--the form, space and environment needed by fish to accomplish their natural life functions . . . natural and impacted characteristics . . . .
- HYDROLOGY--the earth's water cycle and balance (budget) . . .

Table 3. Examples of Components, Their Applications and quantifiable Parameters for Use in a Synthesis of Watershed-Stream Channei Physical Relationships

COMPONENTS (Key/Sub-)	APPLICATIONS (Utility)	PARAMETERS (Analog Indices)
ANALYSIS-	All phases of synthesis	Function of method
BASIN(S)/WATERSHED(S)		
Characteristics	Hydrologic and geomorphic modeling	Area, relief, length, width, slope(s), elevation, vegetation, bedrock . . .
Classification	Evaluate impacts, inventories	Function of method; discussed later.
Drainage system	Modeling streamflow and soil processes/ response . . .	Stream length, order(s), slope, density, frequency, segments . . .
Processes	Mass balances, energy balances, water balances . . .	As listed above plus others . . .
BIOLOGICAL (as related to the physical environment)		Not emphasized in this study, but considered.
CHANNELS		
Classification	Evaluate impacts; inventories	Function of method; discussed later.
Cross-section	Flow capacity, soils	Area, bankslopes, shear stress . . .
Form/geometry	Evaluate changes due to impacts	Width, depth, velocity, perimeter area, flow . . .

Table 3. Components for Synthesis--Continued

COMPONENTS (Key/Sub-)	APPLICATIONS (Utility)	PARAMETERS (Analog Indices)
Hydraulics	Analysis of energy, water surface profiles, momentum forces . . .	Flow, velocity, depth, losses . . .
Hydrology	Flow input, variability, seasonal flows, sediment inputs . . .	Floods, average, lows and flows; monthly flows; characteristic statistical flows . . .
Network	Evaluate soil types on watershed; delivery system to stream segment	Length, pattern, density (see basin drainage system) . . .
Plan	Channel patterns, stream structure, capacity, gradient, geology, soils, horizontal and vertical controls . . .	Curvature, wave length, channel cross-section, P:R sequence, habitat, W:D ratio . . .
Profile (slope)	Energy, shear stress, P:R ratio, transport capacity, stream power, sinuosity, forces, rate of energy expenditures . . .	Substrate size, QSED, slope, flow, change in potential energy . . .
Scale and Size (models)	Evaluate forces, wood transport capacity, diversity, etc. as a function of size in modeling; dimensionless ratios of geometric, kinematic and dynamic properties; similitude . . .	Function of factors being considered . . .
Stability	Response to changes in flow, wood and sediment (environmental inputs); resistance to change; INERTIA ...	Relative strength (cohesiveness) of channel, debris, and riparian conditions; soil, LWD . . .

Table 3. Components for Synthesis--Continued

COMPONENTS (Key/Sub-)	APPLICATIONS (Utility)	PARAMETERS (Analog Indices)
CLASSIFICATION	Organize, categorize and analyze information about regions, areas, basins, subbasins, segments of streams, habitat . . .	Parameters are often indices set to various scales; function of size and level of detail, can use simplified rating scales . . . indices . . .
CLIMATE	Describe hydrologic input, relative moisture levels, freezing conditions, droughts and floods in a region or zone . . .	Yearly and seasonal precipitation, humidity, solar input, temperature, relationships to elevation and aspect; degree-days . . .
DEFINITIONS/GLOSSARY/ NOMENCLATURE	Communication; define terms; provide information management base for data	Function of discipline and applications . . .
ELEVATION	Relates to geology, soils, climate, vegetation, variation in precipitation stream flow, stream type (order) . . .	Above mean sea level; local; differential elevation in watershed or channel; potential energy . . .
ECOREGIONS	Major geographic area with similar climate, vegetation and geology (such as mountain ranges) . . .	Slopes, elevations, climate, stream density, vegetation-elevation zones, wildlife. fisheries . . .
GEOMORPHOLOGY	Landforms related to regional geology, ice and water activity, soils, structure, drainage network . . .	See form of basins above, streams, valleys . . .

Table 3. Components for Synthesis--Continued

COMPONENTS (Key/Sub-)	APPLICATIONS (Utility)	PARAMETERS (Analog Indices)
HABITAT	Location and environment of fish; types; life-stage requirements . .	Velocity, depth, cover, food, diversity, quality, environment . . .
HYDROLOGY	Relationships of water above, on and beneath the earth's surface to water use, budget, streamflow, form of precipitation, geology . . .	Precipitation, streamflow, ungaged streams, flow estimation and prediction MODELS . . .
HYDRAULICS	Analysis of water flow in channels; continuity, momentum, energy; water surface profiles; controls; transport and stream power . . .	See Hydraulics under CHANNELS.
IMPACTS	Indicators of upstream actions and downstream reactions; response variables in stream due to activities (natural and artificial) on the land; direct and indirect; local/regional; cumulative; temporary/long-term; due to changes in land use . . .	Valley geometry; watershed slope, vegetation; soils; mass wasting; road failures; runoff concentration; debris jams; increased sediment load; clogging of substrate; channel widening; shallow depth in summer; elevated temperatures; loss of habitat; D = IR . . .

Table 3. Components for Synthesis--Continued

COMPONENTS (Key/Sub-)	APPLICATIONS (Utility)	PARAMETERS (Analog Indices)
MODELS	Representations of reality; analysis; organization; planning; visualization; data management; research planning; types; physical; prescriptive; descriptive; mathematical; iconoc, hydrologic; geomorphic; sediment transport; channel morphology ...	Function of activity; must be interdependent parameters ...
MONITORING	Periodic or continuous sampling of site characteristics in a stream segment (series of transects) for the purposes of defining natural variability, stability and response among flow, channel and habitat characteristics	Physical and chemical water characteristics; channel geometry; vegetation; substrate; wood; slope; controls; riparian zone ...
PROCEDURES	Data acquisition; storage; retrieval; management; analysis; monitoring; inventory; sampling; analytical (physical, chemical, biological) standards ...	of activity
RIPARIAN	Evaluate conditions of land-water interface to assess interaction of stream with shade, vegetation, litter, erosion (bank) stability ...	Energy, radiation, solar input, shade overhanging cover, undercut banks, wood in stream/on bank; stability ...

Table S.--Continued: Components for Synthesis

COMPONENTS (Key/Sub-)	APPLICATIONS (Utility)	PARAMETERS (Analog Indices)
SEDIMENT	Balance in watershed system; origins; size distributions; impacts on channels and fish habitat; transportation; routing; length of effects (time); potential . . .	Stream power; W:D ratio; flow; specific gravity; gradient; incipient motion; mechanical analyusis of size distribution . . .
STREAM	The fisheries environment; medium for transport of water and "debris" (organic and inorganic); moving body of water; all rivers are streams, but not all streams are rivers . . .	Species utilization: flow variability and seasonality; quality; transport capacity; gradientand geometry in plan, profile and cross-section . . .
SUBSTRATE	Cover; over-wintering habitat; benthic invertebrates; food for fish; indicator species (water quality indicators); sampling spawning gravels; possible classification svstem . . .	Size distribution; slope; depth; stability; armoring: imbeddedness; flow through . . .
SYSTEMS	Natural (real); man-made (artificial); representation of the arrangement and interactions of the interdependent parts of a whole; hydrologic; basins; streams; subsystems; characteristics of; theory; interactive; state; process; alternative; equations; analytical; legal, political, social; resource; CLASSIFICATION . . .	Parameters are a function of the system being described.

- **HYDRAULICS**--analysis of water flow in stream channels based on variable hydrologic input to the stream and its channel response characteristics . . .
- **IMPACTS**--changes in the stream segment, reach or unit . . . caused by changes in watershed conditions . . .
- **MODELS**--incomplete representations of natural processes and man-made (artificial) modifications to the natural environment . . .
- **MONITORING**--measurements of streams to determine baseline stability, changes or the effects of natural and artificial activities, to provide a data base for future management alternatives and decisions . . .
- **PROCEDURES**--step-by-step processes by which data acquisition and analyses are conducted according to standards . . . in support of the monitoring program, etc....
- **RIPARIAN**--land:water interface; sources of organic and inorganic supply to the stream . . .
- **SEDIMENT**--inorganic, mineral material eroded, transported and deposited by streams as a function of streamflow, type of sediment source, the rate of supply, and local gradient controls . . . size of material transported is a function of flow, bed slope, water temperature and the type and amount of sediment source . . .
- **STREAM**--a moving body of water . . . all rivers are streams, but not all streams are rivers . . .
- **SUBSTRATE**--the bed of a stream . . . a life support system . . . resistance to flow . . . overwintering habitat for fry . . .
- **SYNTHESIS**--integration of the individually analyzed components into a larger system . . . . leads to design/conclusions . . .
- **SYSTEM**--a series of interdependent parts which interact and perform as a whole . . . characterized by interdependency . . . a basin and its component parts as driven by its hydrology . . .

Selection of a Pilot Region for Demonstration of Quantitative Modeling

A diverse climatic and geographic region of the State of Washington, the Olympic Peninsula, was selected for use in developing a data base and as a source of examples for the study tasks and components. This region was chosen for four reasons:

(1) The levels of land use on the Peninsula range from heavily impacted on the perimeter, to pristine in the Olympic National Park which forms the central core of the Peninsula;

(2) Two recent studies are available which document the hydrology and the physical aspects of the fisheries environment on the Peninsula (Amerman and Orsborn 1987; Orsborn 1990);

(3) There is a strong interest among the agencies, tribes and other programs (including TFW) in developing the long-range, comprehensive, integrated and effective restoration of the fisheries resources on the Peninsula;

(4) Five of the 19 AMC 1989 monitoring sites are on Peninsula streams, and they include about 22% of the total 1989 stream monitoring length (Ralph 1989a).

In addition there is a considerable amount of background information and data available on the land use, water resources, and impacts on streams and fisheries in many of the Peninsula basins such as the Clearwater River. The undisturbed basins and streams within and near the Park can provide the background information needed to form the baselines from which relative impacts can be evaluated in streams outside the Park.

The balance of this report summary contains general descriptions of the major study components:

- hydrology
- basins
- stream channels
- integration of these components
- classification and
- recommendations.

THE HYDROLOGIC STUDY COMPONENT'

This component of the project was selected for detailed discussion first in Appendix III because: (1) it is the driving force with respect to natural variability in stream flow; (2) changes in flow due to changes in land use, diversions and storage projects are reflected in changes in the stream regime and channel geometry; and (3) fisheries environments are influenced by changes in both streamflow and/or channel geometry. From time-to-time figures and tables from the appendices are referenced in this summary.

By knowing the natural flow ranges, and the annual and seasonal variability in streamflow, one can determine the recent hydrologic conditions under which fish stocks have been functioning. For ungaged streams, such as at monitoring sites, these conditions have to be estimated using hydrologic models. The conditions are called recent because our streamflow records are quite short in the Pacific Northwest. The longest records are on the order of 60 to 70 years. Most records only average 20 years or less in length. Also, hydrological statistics are based on the assumption that future extreme events, such as floods and low flows, will repeat their historical frequency pattern. But, unusual extreme events, both high and low, can be expected to occur at some time in the future.

The hydrology section contains two major parts:

(1) a discussion of the hydrology of streamflow records and methods of analysis using Olympic Peninsula streams as examples; and

(2) a series of hydrologic models calibrated for Olympic Peninsula streams, but which can be applied (with regional recalibration) to any other areas of AMC interest around the State.

Appendix III contains information on two major aspects of hydrology:

(1) data for the analysis of stream flow regimes; and

(2) a series of models which can be used to estimate streamflow characteristics at ungaged sites, or to extend short periods of records.

The hydrologic component is comprehensive so that it can be used to estimate the flow regimes at AMC monitoring and research sites. Streamflow gages on the Olympic Peninsula are used to demonstrate procedures. Precipitation records are sparse and have a high degree of uncertainty when translated any distance, so the only precipitation value used is the average annual precipitation on a basin. This information comes from the average annual precipitation map of the State

'Technical details are presented in Appendix III.

(U.S. Weather Bureau 1965), the basin average is available for each U.S. Geological Survey (USGS) stream gage (Williams et al. 1985).

The concepts and self-adjusting interrelationships of CHARACTERISTIC STREAMFLOWS, those flows of certain frequencies which represent average and extreme flows over the periods of gaged records, are introduced and demonstrated as fundamental parts of the suite of regional hydrologic models.

The procedure (logic) for developing hydrologic models using basin, stream channel and stream flow characteristics are presented in Table 4. The parts of Table 4 can be arranged as follows to summarize the major components of the study:

- **PARTS A-C**: Data on basin characteristics for basins feeding streamflow to USGS stream gaging sites are combined with the statistical flows and calibrated to form "regional" (provincial) hydrologic models. Stable parameters which will not change much over time (such as basin area and relief) are selected.

- **PARTS D-E**: At each of the USGS gaging stations, calibration measurements of streamflow are used to relate the channel characteristics of width, depth, velocity and flow area to discharge. Then, for selected characteristic flows (such as the average daily low, average annual and average flood flows) the width, depth, velocity and flow area are determined for each of the flows. These channel geometry dimensions are related to each characteristic flow to give "regional hydraulic geometry" models. The low flow relationships are the most variable, because the bottoms of many channels change shape on a year-to-year basis. The calibration records have to be evaluated for different sets of years to determine whether or not significant changes in channel size and shape have been occurring. The most recent records were used in the reference report by Amerman and Orsborn (1987).

- **PART F**: Because characteristic flows can be related to basin characteristics, and because those same flows can be related to channel characteristics (e.g., width, depth, velocity, area . ..), then, **BY SETTING THE TWO RELATIONSHIPS EQUAL TO EACH OTHER**, the channel characteristics can be shown to be a function of (dependent upon) the basin characteristics.

These interrelationships between basin and channel characteristics, developed by using certain characteristic streamflows as the common linkages, when calibrated for each geologic-climatic-topographic-hydrologic province, provide the analytical bases for synthesizing these provincial characteristics into a system for classifying basins on the basis of their own parameters, their hydrologic variability and stability, and the channel geometry-flow relationships of the streams in those provinces.

Table 4. Logic for the Development of Hydrologic Models

A. BASIN CHARACTERISTICS

1. Relate area, relief, stream length, etc. to each other to reduce future measurements and to characterize geologic provinces.

B. STREAMFLOW CHARACTERISTICS

1. Generate available streamflow data from existing and discontinued gages, and miscellaneous measurements.
2. Establish baseline, long-term gages in each hydrologic (climatic) province.
3. Cross-correlate short- to long-term gages to extend records and improve reliability of characteristic flows (low, average, floods, and monthly).
4. Do computer runs of flow frequencies, durations and probability distributions, unless already completed by USGS.

C. COMBINE BASIN AND STREAMFLOW CHARACTERISTICS TO GENERATE THE REGIONAL (PROVINCIAL) HYDROLOGIC MODELS . . .

1. Select gaged basins to set aside for testing model.
2. Relate characteristic flows to basin characteristics in part (A).

D. CHANNEL CHARACTERISTICS

1. Select sample of channels with typical, but various, geometric shapes which are deformable (not constrained by bedrock, hardpan, etc.), in province.
2. Relate flows to hydraulic geometry of the sample channel sections (width, depth, velocity, wetted perimeter, flow area, bankfull flows, bed materials and gradient).

E. COMBINE STREAMFLOW AND CHANNEL CHARACTERISTICS TO GENERATE CHANNEL MORPHOLOGY MODELS . . . . Called Hydraulic Geometry.

F. COMBINE BASIN AND CHANNEL CHARACTERISTICS TO GENERATE BASIN-CHANNEL MORPHOLOGY MODELS . . . . Channel geometry depends on basin geometry.

G. TEST THE HYDROLOGIC MODELS

1. Use gaged sites that were set aside.
2. Estimate flows at ungaged sites in each province.
3. Verify estimates with miscellaneous measurements at ungaged sites.
4. Expand the calibration model for easily accessible and selected remote basins.
5. Define hydrologic and geologic anomaly areas for further study.

H. CONSOLIDATE AND ASSESS RESULTS

1. Define stream gaging needed to complete calibration of models in anomaly areas.
2. Make miscellaneous measurements to refine calibration.

tlighlights of the hydrologic study component are summarized below. Emphasis has been placed on providing methods and operating rules which can be applied to any AMC site throughout the State. The wide range of Peninsula precipitation (20-200 inches per year) covers the range of conditions which could be expected in forested areas any place else in the State. Various topics which are examined include:

- the interrelationships of forest types, precipitation and elevation on the Olympic Peninsula.
- the study area (Olympic Peninsula) subdivision into Provinces based on climate and major topographic divides; analysis of the streamflow records shows the similarities and dissimilarities of streams within and between the provinces.
- the analytical basis and uses of the U.S. Geological Survey (USGS) data base.
- the variability of streamflow throughout the Peninsula as shown by relationships between low, average annual, monthly and high flows.
- the sources of uncertainty in streamflow data, and methods to reduce uncertainty at an ungaged site.
- various statistical methods for analyzing streamflow records, and their relationships to fisheries life-stage requirements, and responses to the effects of land-use changes.
- the bases for, and the uses of, CHARACTERISTIC FLOWS for modeling and as indices for stream classification.
- examples of models, methods and the logic for developing regional hydrologic models for streamflow estimation at ungaged (monitoring and research project) sites.
- procedures for deciding which models should be used and how to check the estimated flows at ungaged sites.
- the importance of, and methods for testing, whether or not short-term stream flow records (less than 10 years) were taken during wet, average or dry cycles.
- the variability in hydrologic models throughout the Olympic Peninsula.

The drainage basin, which regulates the timing and amount of streamflow at a particular site, is examined next from various perspectives.

THE DRAINAGE BASIN STUDY COMPONENT*

Introduction

Basins are considered from various perspectives of different analysts, and then as natural hydrologic/geomorphic systems within which stream networks are developed. The physical characteristics of the basins and networks can be quantified and correlated to each other and against streamflow to provide the linkages needed to analyze the continuity between precipitation, streamflow, channel geometry, sediment transport and fisheries habitat. Examples of basin characteristics and their analogies to components of the hydrologic cycle are demonstrated with mathematical models in Appendix IV.

In working with any problem we are forced to arrange our thoughts and information into some organized, systematic framework or model. Our resource models are nothing more than incomplete representation of reality, or of the real (natural) world. We use descriptive models of a watershed and its resources, and we use other types of models such as: analytical (what if . ..?). prescriptive (how we think something will be); dynamic (involving change and forces); and mathematical (representing processes and relationships) . . . .

One focus of this report, and the focus of some agency and tribal programs, is the fisheries resource . . . a natural resource which we are considering within the basin system. For anadromous species we have to consider the conditions governing their upstream migration, spawning, incubation, rearing and downstream migration environments. For resident fisheries the considerations are similar without the extensive ocean migration. Other global and international environmental factors affect the fish during ocean-rearing. Our focus is on actions and reactions (impacts and responses, causes and effects) within the basin-forest-stream-fisheries environment, and linking those components.

Basins and Potential Impacts on Fisheries

The primary project focus is to concentrate on the assessment of physical land use impacts on fisheries environments in order to meet the objective of minimizing future impacts. It does little good to provide buffer strips in perennial second- or third-order channels if clear cutting is allowed across first-order channels. The gravity force of the devegetated soils suddenly exceeds the restraining friction of the soils on the bedrock (without the binding root structure). This occurs more frequently when the contact surface is lubricated by infiltrated water. Result--the soil-rock-vegetative mass travels downhill until it reaches a land or stream slope which is too mild (or a channel-valley segment that is too narrow) to transport the debris--usually in a second-, third-, or higher-order stream of high fisheries value (McCrea 1984, U.S. Forest Service 1980).

*Technical details are presented in Appendix IV.

Now it is the stream's turn to react to the new set of environmental considerations that were caused by factors beyond its control . . . man's disturbance of a hillslope (action), and the slide (reaction). Also, the construction of access roads, which in turn intercept and concentrate runoff, causes a majority of logging-associated slides (McCrea 1984, Rice et al. 1972, Swanston and Swanson 1976). Rut quantification of instream impacts as functions of land use changes is a very complex and difficult process (Slaymaker and Jeffrey 1969). Land use changes, driving forces and responses are all interdependent transients and shift in their relationships from year to year.

How will the stream respond to this barrier to the downstream migration of the flow? For every upstream action there is a downstream reaction. In this case, there will be an upstream reaction . . . ponding of the water until the stream overtops or cuts through the barrier. The water will attempt to restore the stream to its original gradient (equilibrium) by removing the barrier. Materials will be removed if the forces of the water exceed the resisting forces of the weight of the particles and their interlocking resistance with other particles and the channel boundary.

The downstream reaction in this case comes from release of particles from the debris pile. The water forces are converted from static (upstream pool) to velocity as the stream adjusts to the new gradient and tries to erode the downstream face of the barrier. If the net pressure against the upstream side of a wood-debris barrier debris pile exceeds the resisting friction force of the pile on the boundary, the debris will move downstream as a traveling sluice gate with high velocity water flowing beneath it--removing substrate down to bedrock. Now what can we, or should we, do?

We are faced with the dilemma of a totally altered physical stream environment, converted from a naturally productive one to an unnatural, inert, uniform, solid-bed, unproductive stream--void of diversity. It is analogous to converting a natural channel in an urban stream environment to a concrete flood control channel.

Of course, not all natural or artificial impacts affect the fisheries-stream environment to the degree that this example debris slide did. There are numerous, more subtle, but cumulative and lethal impacts which can occur due to both natural and/or artificial causes: droughts, thermal barriers, a channel-altering series of major floods, altered stream flow regimes, and changes in runoff and the hydrologic balance due to major changes in land use. These potential impacts are discussed in more detail in Appendix VI in which the study components are integrated.

We are considering the natural, water-oriented resources within a basin system and how these resources are interrelated and interdependent. But, the husbandry of the fisheries resource is totally dependent on what happens to the other land-vegetative-water resources (trees, sediment and water) within the land-water system of the watershed. Therefore, in order to consider these matters further the basin is examined from various perspectives in Appendix IV.

Human Perspectives of Basins

How do we perceive watersheds or drainage basins? Do we envision them as being a feature on the surface of the earth, defined by a topographic divide, above some site or location on the stream? Are they something we have viewed from the air, on a relief map, a topographic map, on aerial photographs, or as a three-dimensional sketch on a piece of paper? Are basins something you have visualized as some upslope, land structure rising above you while standing by a stream? Or perhaps. a basin is the view of a headwaters basin as seen from a vantage point above timberline. How does one relate this description to others?

One of the major problems associated with interdisciplinary team projects is communication. No, it is definitely the major problem! Until team communication is efficient (open, and unconstrained), problem definition cannot be accurately accomplished. Unless problem definition is thorough, the best problem solutions cannot be achieved--ever! If team and project objectives (they are different) cannot be stated in measurable terms their achievement cannot be fully realized, and possibly not even recognized. Are we discussing the same perceptions of basins, streams, habitat, substrate, spawning gravels, aggregate . ..?

We have to settle on some basic definitions of why, and methods describing how we are going to approach the physical analysis of forest-stream-fisheries environments within drainage basins. What are our objectives? Are we trying to: (1) increase the effectiveness of our decision-making processes; (2) better sustain the limited forest and fisheries resources we have; or (3) improve our individual and collective skills?

Considering the three objectives stated above it would seem that objectives (1) and (2) are personal-team-program-agency-moral-ethical-patriotic objectives. Objective number (3) is a method whereby (how) we can be more effective as individuals, team members and managers in achieving objectives (1) and (2) (what we want to accomplish).

Analysis of Basin Characteristics

As with any other scientific or engineering endeavor, the acquisition, storage and/analysis of information requires standard procedures. Geomorphic analysis of drainage basins, and the combining of basin characteristics with streamflows to generate hydrologic models requires that procedures and data sources must be standardized. Typical parameters used to analyze basins and to develop hydrologic models are listed in Table 5. The basin and hydrologic characteristics to which the measured properties are related are listed in the last column. The measured characteristics in the first column are considered to be analogous to (to represent in models) the physical conditions and processes in the last column of Table 5.

Table 5. Sample of Basin Geomorphic Characteristics Used in Regional Basin and Hydrologic Analyses

Property, Symbol	Dimensions*	Relates to:
Stream Length, LS	L	Perennial stream networks, percentage of input becoming surface runoff (output), soil type, geology, basin storage, contribution to low flow
Drainage Length, LD	L	All drainage channels including intermittent; floods
Basin Length, LB	L	Aspect ratio LB/WB; flood concentration time
Basin Relief, H	L	Potential energy, form of precipitation, ground cover, etc.
Basin Width, WB	L	Rectangular equivalent derived from A/LB = WB
Basin Area, A	L^2	Catchment size, ability to catch precipitation
Stream Density, LS/A	L^{-1}	Soil types and runoff conditions especially low flow; method of determination should be standardized; blue lines on USGS maps
Drainage Density, LD/A	L^{-1}	Relates to soil types and floods
Channel Slope, SC		Average rate of expenditure of energy as flow moves through the basin
Stream Order, SO (or drainage order)		Basin and stream location in the total basin; size of stream channel or basin; relates to types of fish food sources; vegetation, etc.

*L is dimension of length with units such as feet or meters.

Summary of Appendix IV

This appendix covers technical details associated with processes in basins, and the analysis of basin characteristics and their relationships to those processes. In summary, Appendix IV contains discussions of:

- impacts as a function of basin and disturbance sizes,
- the relative sizes of hydrologic events (floods) and basin areas,
- common objectives for access roads and streams,
- the components of the basin system including the topographic land area, the stream network, a segment of the stream network, a riffle:pool unit, and the fish within the unit,
- interactions among the physical components of the land-water-basin system, as described by the measurable characteristics of the basin, its hydrology, stream channels and stream loads (water, organic and inorganic "debris"),
- the characteristics of the basin system which can be used as stable classification characteristics, and those which can be used as deformable response variables,
- the basin as an integrator of precipitation which yields certain amounts of streamflow in certain sequences within certain flow ranges and time periods (the streamflow regime),
- the information needs, and sources of that information, for conducting drainage basin analyses, including average annual precipitation as a basin characteristic and as a classification tool, and
- some quantified examples of basin characteristics and their interrelationships.

A sample geomorphic analysis is developed for Lebar Creek, a tributary to the South Fork Skokomish River on the Olympic Peninsula. The results of this analysis are used later in Appendix VI wherein the basin, flow and channel characteristics are combined (integrated). The application of basin characteristics to classification systems is examined in Appendix VII.

STREAM CHANNEL CHARACTERISTIC3

Introduction

The three-dimensional geometry of STREAM CHANNELS is discussed from the perspectives of hydrology, hydraulics, sediment transport and fisheries habitat. The streamflow regime (its hydrologic characteristics including debris load), and channel responses to changes in that regime, are presented and related to changes in physical characteristics of fisheries habitat. Examples of hydraulic geometry models and regional variability in channel size are evaluated, and impacts caused by increased sediment loads are demonstrated. Stream power, sediment transport and channel geometry are integrated to demonstrate the influence of excess sediment on channel flow capacity and changes in the response variables of flow top-width, mean depth and mean velocity. Hydraulic relationships among flow and habitat availability in pools and riffles in steep mountain streams are summarized.

The logic from Figure 1, for relating the various parts of a basin to the stream channels in the basin system, is repeated below to restate the linkage concepts:.

> If part of the precipitation received by a basin is released as streamflow and, if the geometry of the stream network is formed by this streamflow, then there should be physical relationships among the stream network geometric characteristics and the stream flow regime; and if a subset of watersheds are within a hydrologic province and have similar geological surface deposits, then the geometric characteristics of the streams should be similar in all basins within the province; and, if the interaction of streamflows and freely deformable stream boundaries are governed by the same hydraulic forces, then stream channels of different sizes should have comparable dimensionless geometric and streamflow ratios. (Stypula 1986).

This logic describes the linkages between climate, hydrology of streamflow, drainage networks (as discussed in the last section on basin characteristics) and the size, shape, slope and patterns of stream channels in a particular segment. Upstream actions cause stresses which are always translated along the path of least resistance, downstream along the steepest slope until the flow reaches a slope which does not have the stream power to carry the extra load.

Assessing Channel Changes

Stream channels change in size and slope as a function of natural and man-made upstream actions in the basin. This is demonstrated in

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[3] Summary of the technical details which are in Appendix V.

Appendix V (page V-9, Figure V-3) wherein the low flow top width decreased from 70 feet to 20 feet as a result of a 1982 flood.

The USGS gaging station calibration information, measured numerous times each year, shows shifts or scatter sometimes in the relationships between water surface width, mean depth, mean velocity, channel flow area and streamflow--all of which are collectively termed HYDRAULIC GEOMETRY. Geometric properties are related graphically and in equation form. The amount of change in channel geometry, and the direction of change in size (increase or decrease) are in direct response to changes in the streamflow (and load) regimes. A stream which is "in regime" is in balance between the load (organic and inorganic materials), its streamflow and the local slope.

When the stream channel goes "out of regime," or out of balance, then the resultant changes in channel geometry will change the habitat mixture and diversity. Depending on channel steepness, and the distance between channel/valley geologic controls, and the stability of the channel boundary materials, changes due to regime changes can range from minimal to drastic. Steeper channels with more stream power (flow times slope, capacity to move load) would tend to remain more stable during regime shifts. But, stream reaches with less stable boundaries expand and contract in direct response to long-term changes in the flow or load regime.

The procedures for quantifying channel changes under natural and man-modified basin conditions require a data base which should include:

- baseline information under natural conditions prior to land use modification, or baseline data on similar, undisturbed streams;

- historical records of land-use changes and of channel changes; and

- modeling estimates combined with on-site stream flow documentation; where possible, some form of precipitation records should be available to document trends and changes in the water inputs to the basin.

Otherwise, if any of these components of the data base are missing then the assessments will be:

- qualitative without knowing at least the relative cause and effect relationships;

- transient effects, such as changes in transpiration and runoff due to changes in vegetative growth, will possibly be large enough to mask other effects; and

- the evaluation will be made from a shifting frame of reference

Otherwise the evaluations of the response variables of channel geometry can be only qualitative. Expectations for channel changes due to a variety of causes are listed in Table 6 from Kondolf and Sale (1985) as developed by them from numerous references.

Table 6. Long-term Channel Adjustments In Response To Specific Perturbations (Modified From Kondolf And Sale 1985)

Event	Typical Effects	Probable Channel Adjustments
Major flood:	Instantaneous channel widening	Subsequent narrowing with
♦ Aggradational	♦ Aggradation	♦ Incision into flood deposits
♦ Degradational	♦ Degradation	♦ Reestablishment of floodplain and reelevation of channel by deposition by deposition
Increase in sediment loads	Aggradation, possibly inducing channel instability	Best case: subsequent clearwater flows flush excess sediment, degrading bed
		Worst case: aggradation-induced instability of banks
Land-use changes:		
♦ Forest to agriculture	More rapid runoff, increase in sediment, aggradation, sediment storage in floodplain	Geometry adjustments; widening; pools fill with sediment; substrate finer grained
♦ Agriculture to forest	Less flashy runoff, decline in sediment yield	Geometry adjustments; sediment loads may not decline for many decades sediment comes out of floodplain storage
♦ Change in riparian vegetation	Banks more or less resistant to erosion, channel width change and instability. Time scale: months-to-years	If riparian corridor restores, stable geometry may develop or instability could persist. More vegetation leads to channel narrowing by encroachment. Time scale: years-to-decades.

Table 6. Long-term Channel Adjustments In Response To Specific Perturbations (Modified From Kondolf And Sale 1985)--Continued

Event	Typical Effects	Probable Channel Adjustments
Urbanization of basin:		
• Construction phase	Sharply increased sediment yield from bare ground, flashier runoff	Geometry adjusts to higher peak flows by widening; fine-grained sediment covers substrate and fills pools; may aggrade or degrade, but storage of sediment in-channel likely
• Postconstruction phase	Decreased sediment yield from pavement and vegetated areas, runoff very flashy through storm sewer systems	Geometry remains wide (or widens further) to accommodate higher peaks; runoff brings less sediment from uplands so flows remove sediment stored in channel during construction phase
Inter-basin water transfers:		
• Dewatered basin	Reduction in capacity and compe-tence to transport sediment	Aggradation at confluences of sediment-laden tributaries; widening or narrowing both possible
• Receiving basin	Increase in sediment transport capacity and competence	Bank erosion likely as stream expends excess transport capacity; channel widening and deepening probable

Table 6. Long-term Channel Adjustments In Response To Specific Perturbations (Modified From Kondolf And Sale 1985)--Continued

Event	Typical Effects	Probable Channel Adjustments
Dam construction upstream of study reach	Sediment from upper basin trapped in reservoir, so sediment load to channel downstream (usually) much reduced; flow regulation typically reduces flood peaks, thereby reducing sediment transport capacity and competence	Degradation most likely but aggradation also possible on gravel-bed rivers; coarsening of bed material (armoring of gravel beds likely); narrowing of channel most likely, but widening or no change common as well; deposition of fine sediment in gravel possible (due to lack of flushing flows)
Channelization	Channel usually straightened and limited to a smaller high-flow width	Channel and bank erosion producing a meandering pattern, with pools and riffles developing; upstream and downstream reaches may also be destabilized

Summary of Appendix V

Topics include:

- the interrelationships of channel geometry, hydrologic regime, hydraulic routing of the flow through the channel segment, and the fluid mechanics of flow interaction with instream objects to form fish habitat.

- these interactions can be viewed from the perspectives of

    - flow related to channel shape, called HYDRAULIC GEOMETRY;

    - the combination of flow and channel slope to describe STREAM POWER which describes the capability of the stream to transport load, and the size of the stream bed armor; and

    - combining streamflow with habitat features to analyze habitat availability.

- the channel segment, and the riffle:pool subsystem, are analyzed with respect to their positions in the basin-stream network-reach system.

- fundamental equations of hydraulics are related to channel geometric characteristics which are also fish habitat parameters.

- data sources for channel information, as well as standard methods for analyzing that data;

- channel geometry and flow relationships for 20 Peninsula gaging stations and regional models which relate channel dimensions to average low, average annual and average flood flows;

- example calculations showing the variability in actual channel sizes compared to sizes estimated using the regional equations;

- the influences of horizontal and vertical controls on channel geometry and sediment transport, and the concept of "base level" as a control on channel profile:

- influences of sudden excess loads of sand on stream channel characteristics;

- variations in flow resistance as a function of flow;

- the channel width to depth ratio as a function of its wetted boundary (perimeter), flow area, stream power and sediment transport;

- classification and stability of channels related to their plan-view patterns and sediment transport capabilities;

- hydraulics and habitat in steep stream channels during high and low flows; and

- some additional sediment transport considerations.

The next section describes the integration of hydrologic, basin and channel characteristics to demonstrate physical linkages among them, prior to the application of these characteristics to classification systems.

INTEGRATION OF HYDROLOGIC, BASIN AND STREAM CHANNEL CHARACTERISTICS WITHIN THE BASIN SYSTEM[4]

Introduction

Each major physical component of the basin system has been examined separately---the basin, its hydrology, and its stream channels. In order to use them in a classification methodology, their linkages must be developed in order to demonstrate their interrelationships (synthesis) as continuous, interfacing and interdependent parts of the same system.

Prior to demonstrating the linkages of these three components, several perspectives of basin processes are reviewed. The perspectives provide different ways to view influences such as: flow regime modification, logging and road building activities, log and debris jams and excess sediment loads.

Methods of Component Integration

Basin characteristics have been used in developing hydrologic models by relating them to certain characteristic low, average and high stream flows. Those same stream flows can be related to channel geometric characteristics. For example:

$$\text{Average Streamflow} = a\ (\text{Basin Characteristics})^b$$

where (a) is a coefficient and (b) an exponent, determined from the regional data.

Also,

$$\text{Average Streamflow} = c\ (\text{Channel Characteristics})^d$$

where (c) and (d) are a coefficient and an exponent determined for a set of stream channels which are part of the same region. By setting the second relationship equal to the first, channel characteristics can be

[4]Summary of technical details which are in Appendix VI.

demonstrated to be related to (a function of, dependent on) the basin characteristics.

Also, if the average annual flow is written as a function of the average annual precipitation (P) and the drainage area (A), these also can be equated to channel geometric characteristics such that

Average Flow = a (PA) = c [Channel Width, depth, velocity, or area in combination)^{d}

The physical linkages with fisheries needs lie in two main topic areas:

(1) the seasonal life-stage functions of the various fish species in a system; and

(2) the natural and/or altered streamflow regime in the critical habitat and critical passage reaches of the stream. Flow alteration, outside the range of natural extremes, in either the quantity available or the time distribution throughout the year, can adversely impact fisheries.

The integrated linkages among basin, streamflow, channel geometry and spawning habitat are demonstrated for a series of streams in Western Washington (Orsborn 1981) based on data from U.S. Geological Survey studies conducted for the Washington Department of Fisheries (Collings 1974).

All the approaches used to demonstrate the integration of hydrologic, basin, channel and fish habitat characteristics show that the linkages exist. Also, within each component there are other linkages which have already been demonstrated in sections and appendices previously described. For example:

BASIN PARAMETERS:

- Stream Length (LS) is related to:
  - drainage basin area (A),
  - basin energy $(A)(H)^{0.50}$, and
  - basin annual precipitation volume (PA).

STREAMFLOW PARAMETERS:

- Characteristic Flows (Q CHAR = Q LOW, Q AVE, Q HIGH) can be related to each other:
  - Q LOW = (Q AVE)^{3}/(Q HIGH)*,

- monthly flow as percentages of the long-term average annual flow,

- correlation of flows at one site to another, and

- ratios of the characteristic flows within a region (hydrologic province).

CHANNEL PARAMETERS:

- Discharge (Q) can be related (at a site) to:

- water surface top width (W),

- mean hydraulic depth (D = A/W),

- cross-sectional flow area (A),

- wetted perimeter (P) which is the contact surface between the water and the channel bed, and

- the mean water velocity (V).

In the next section on classification, separate regional combinations of streamflow, basin and channel characteristics are used to group streams and basins into subregions. Then, the separate component combinations are integrated (equated, interfaced, linked) with combinations of characteristics from the other components.

APPLICATIONS OF HYDROLOGIC. BASIN AND CHANNEL CHARACTERISTICS TO CLASSIFICATION[5]

Introduction

> A classification system does not stand by itself in stream evaluation analysis. Streams are difficult to understand when only the existing state is known; therefore, they must be placed in perspective as to where they have been and where they are going.------A classification system must be developed as it is the main motor in the evaluation procedures (Platts 1983).

This partial quotation from Platts (1983) was heard from many participants from different disciplines at the expert workshop on classification in June, 1989 (Flaherty 1989, summarized in Appendix VIII of this report). The classification system should allow investigators to relate past and prospective conditions and to be able to estimate the

[5]Summary of Appendix VII. Due to the technical details discussed in Appendix VII, this summary is cross-referenced to tables and figures in the appendix.

degree of change based on an assumed change (e.g., the size of a flood of a certain frequency).

In Appendix VII various methods which can be used to categorize streams, on the basis of their flow, basin and channel characteristics, are demonstrated and evaluated.

Hydrologic Classification

Dimensionless ratios are commonly used in modeling to avoid scale effects, and this is a simple but effective tool for classifying streams on the basis of their "characteristic flows."

The indices used include:

- ratios of characteristic flows (refer to Table VII-l, page VII-3),
- a discussion of how the ratios vary throughout the Peninsula,
- the variability in average annual flows by subregion (Table VII-4, page VII-II); (the regions set up by the AMC and hydrologic provinces are jointly displayed in Figure VII-I, page VII-Z),
- unit flow values per square mile (csm) are developed for several of the characteristic flows, as well as for the maximum peak floods of record, to provide an estimate of the upper limits of streamflows in each region/province,
- dimensionless duration curves using flow ratios of average high to average low, and average annual to average low are used to group streams (refer to Figure VII-3, page VII-IO),
- regions are defined on the basis on plotting one dimensionless ratio against another as shown in Figures VII-5 and VII-6 (on pages VII-14 and -16, respectively). These ratio plots show definite relationships among flood, average and low flows by Province, and which streams are inconsistent.

Some types of flows cannot be directly related to certain other flows. For example, low flows are usually controlled by geology (groundwater supply) and glaciers. The variability of average annual flows is controlled by the time distribution and rate of precipitation in a year, above the ground surface. Therefore, classification of streams using just these two flows derived from different processes would not be appropriate. But, the low flows are part of the total flow history which makes up the average annual flow. Also, one has to consider the accuracy with which certain flows can be measured; many times maximum peak floods of record have to be estimated by calculating them indirectly from high water marks, and channel cross sections, which may have partially filled since the flood receded.

Other classification indices using flow characteristics are:

- unit peak flood, average flood, average annual and average low flow values in csm as shown in Tables VII-5 and VII-6 on pages VII-18 and -19;

- combined ratios of unit flow values regionalize the basins as shown in Figure VII-7 on page VII-20; and

- flow levels could be ranked (e.g., the highest flood would be 1) and the sum of the indices for all the flows would categorize the relative level of water activity among the basins on the Peninsula, and average annual precipitation could be included as one of the indices.

Basin Classification

The basin characteristics considered for classification were those which can be measured, combined and used to develop quantitative relationships among basin, flow and channel characteristics.

- the combination of $(PA)/(LT \cdot H^2)$ which represent annual basin precipitation (input = PA), divided by the total stream length (LT) and basin relief $(H)^2$ above a site. The stream length and energy terms represent a basin's capability to move flow and load out of a basin. This combination of terms has been found to have a consistent relationship to basin relief (H) over wide ranges of all the variables.

- basin input (PA) is related also to stream length (LT or LST), and to basin energy $(A)(H)^{0.50}$.

- The interrelationship of average annual flow to basin energy and average annual precipitation.

- An examination of the basin characteristics of Lebar Creek, a second-order stream which was used as a pilot study area within the South Fork Skokomish River basin on the Olympic Peninsula.

Channel Geometry Classification

Examples of classification based on channel characteristics include the use of: (1) regional hydraulic geometry; (2) water surface width to depth (W/D) ratio developed from their two regional equations; and (3) W/D as a function of basin energy, $(A)(H)^{0.50}$.

The W/D relationships developed by steps (2) and (3) gave very similar results. Most of the gaging stations fell within three groupings except for one which had a 100 percent deviation in (W/D) from the expected value. This was most probably due to heavy logging activity on the basin.

Limitations on the accuracy of this W/D analysis include:

- only the most recent data was used in the analysis;
- variability in hydraulic geometry over time was not analyzed because the magnitude of such a separate study was beyond the scope of this project.

But, channel geometry variability was sampled at USGS gaging stations, and it was noted that usually only the low flows are affected by changes in the channel bottoms. These sites are selected for their stability. Monitoring sites for the AMC program would not necessarily be selected based on their stability.

The consistency of the relationships developed between W/D and basin energy demonstrated the validity of this method of stream channel regional classification. Using such a calibration based on natural streams in a region, streams that had been altered could be identified.

Stream channels in plan view patterns (straight, braided or meandering) were not included in the classification system because of the other work already done on valley classification (Cupp, 1989). But, there are physical interties among channels in plan, profile and cross section. Cupp's (1989) classification work has addressed ranges of slopes (profile) and related those to channel patterns (plan) and valley segment type, but physical quantification of the interties has not been accomplished. This approach would provide a method of predicting adjustments in channels in three dimensions based on variations in flow and load coming into the segment.

At the end of Appendix VII the methods developed for classification are summarized and cross-referenced to pertinent tables and figures.

SUMMARY OF WORKSHOP ON CLASSIFICATION[6]

On May 24-26, 1989, a workshop on stream and basin classification was sponsored by the AMC for a selection of experts in the field. The AMC sent its study plan (AMC 1989) and a set of guidelines to the participants prior to the workshop. The detailed transcript was reported by Flaherty (1989).

Many of the concepts, experiences and approaches related by the attendees were explored further and incorporated into the preliminary draft report for this project (Orsborn 1989). The general feeling of most TFW personnel was that we may be able to utilize parts of other classification systems, but we will have to develop another classification system to fit out unique Pacific Northwest conditions.

At that stage in the overall'classification effort, this was a predictable and logical response. As more information is developed and

[6]Reported in more detail in Appendix VIII.

more experience is gained, the AMC classification system for basins and streams will no doubt improve the utility of earlier systems upon which it was initially based.

SUMMARY OF COMMENTS ON THE AMC MONITORING PROJECT

Involvement in the monitoring project, by the principal investigator of this physical systems modeling project, began prior to the May, 1989 initiation of the modeling project, and has continued. Drafts and subsequent versions of the Stream Ambient Monitoring Field Manual (Ralph 1989a), and other documents, were reviewed.

The monitoring program serves several unique purposes in the TFW program:

- it trains persons in a more holistic approach to gathering stream data, and in the purposes for that data;
- the monitoring project is the testing ground for proposed methods of data acquisition, data management, classification procedures and management implications; and
- it provides the only real-world environment in which all aspects of the TFW program can be tested and adapted, and as the persons involved in the TFW program become more aware of the scale and magnitude of TFW problems, the basins will reveal the best solutions.

In Appendix IX the assessment of the monitoring program uses the AMC 1990[7] plan as the skeleton for the comments.

RECOMMENDATIONS

In making these recommendations the primary purpose that guided them was to achieve improvements in the classification and monitoring programs. The initial timing of this project called for about two months of effort. This culminated in a preliminary draft report (Orsborn 1989), which evolved into a second draft report (Orsborn 1990) and which has now developed into this third version. The evolutionary process in the modeling project is mentioned because it is a model of the whole AMC/TFW process . . . steps have to be taken and proven to an acceptable level before other steps can be taken in the adaptive management process.

- Contact the USGS about repeating some of the habitat investigations they completed for the Washington Department of Fisheries in the 1970s (Collings 1974):

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[7]TFW/AMC. 1990. Extensive stream survey project study plan of June 26.

- these studies gathered extensive and sell-documented instream flow and habitat information on some 20 streams in Western Washington;

- the streams covered a wide variety of geomorphic, hydrologic, geologic and land use conditions;

- all the study sites were established near USGS gaging stations; and

- almost 20 years have passed since the studies were completed..

Therefore, these study sites offer ideal situations in which to evaluate channel and habitat changes over time. It is recommended that the suggested study include the following activities:

- form a task committee within AMC of one-to-three people to assess this proposal.

- consider which basins might best serve AMC/TFW needs in terms of classification and monitoring tasks.

- contact the USGS office in Tacoma to ascertain:

  (1) the availability of the original study records;

  (2) the USGS's interest in possibly upgrading the study at certain sites on a cooperative basis with the AMC;

  (3) whether the data from the first study would be available to AMC if the USGS could not conduct the new study; and

  (4) whether the USGS would be able to complete the study, assist with it and/or provide the data files within a reasonable time frame to be determined by the task committee.

- The task committee would report its findings to the AMC.

- Assuming a decision is made to proceed with the project the AMC would need to:

  (1) select the sites which would best suit the AMC objectives;

  (2) determine which sites have good documentation of land-use changes which have occurred since the first studies were completed; and

  (3) formally request a proposal for the study, either from the USGS, or from other contractors, depending on the results of earlier inquiries.

This project would be very beneficial to the AMC program in that it would provide information on changes in stream channels, streamflow distribution and fish habitat which could be correlated with basin changes or with no changes in some basins. The results of this study could provide a solid foundation from which the monitoring program could be modified, improved and streamlined.

- **There may be another instream flow data base which may not have been tapped by AMC. This consists of all the instream flow studies which have been conducted by federal and state agencies and consultants in conjunction with hydropower applications and the relicensing of projects.**

  If this data base has not been assessed, it should be, to determine how it might be used to supplement the monitoring and classification program data bases.

- **Forest Service instream flow, GAWS and long-term trend monitoring sites should be explored as possible supplements to the statewide monitoring and classification data bases.**

With the possible inclusion of the recommended supplemental data bases (USGS, BLM, USFWS, IFIM and USFS), within two to three years the monitoring program may be on a solid enough foundation that it could be refined and adjusted to address problems which are not now apparent.

- **Also, stronger interaction should be developed with the Forest Service for each Forest in each region of the state where AMC monitoring sites are located. The forests (e.g., Mt. Baker-Snoqualmie) are developing both GIS data bases, and Hydrologic Cumulative Effects Analyses. Watershed processes (activities and channel conditions) are being documented for each watershed, and IDTs are focusing on channel conditions. This information would be very helpful to the AMC for its monitoring and adaptive management processes.**

- **A project should be undertaken to evaluate the hydrologic data bases in each region where AMC monitoring sites are located. Part of the project would calibrate hydrologic models for each region using the methods described in Appendix III of this report.**

- **Also, in each monitoring region, analysis should be conducted of the calibration data for each USGS gaging station to determine changes in hydraulic geometry over time in altered and unaltered basins. The channel changes should be related to the streamflow record, and major (and cumulative) land-use changes should be documented for basins showing significant channel changes, similar to the first recommendation.**

- **An evaluation of the classification indices from this project (basin, streamflow and channels) should be developed for each** monitoring region. These last three recommendations will help establish a stronger foundation for the AMC monitoring program, the stream response model and decision-making efforts.

- In developing the stream response model, the "downstream hydraulic geometry" type of model in this report can be used as a relative evaluator. For example, Figures V-7 and -8 (pages V-15 and -16) indicates that if there is a percentage change in the average flood, then there will be a certain adjustment in width.

Percent of Index Flow (%)	Index Flow (cfs)	Width (ft)	Area (ft^2)	Depth (ft)
100	1000	62.6	170	2.7
120	1200	67.6	198	2.9/2.5*
140	1400	72.0	224	3.1/2.4*
160	1600	76.3	251	3.3/2.2*
180	1800	80.1	277	3.5/2.1*
200	2000	83.8	302	3.6/2.0*
Change:	1000	21.2	132	+0.9/-0.7
% Change:	100	34.0	77.8	+33.0/-26.0

First number is depth of flow if the channel confines the new average flood within its banks without widening. The second depth is for the average flood of 1000 cfs after the channel has been widened.

This example is only an indicator of expected trends. The actual changes would depend on the hydraulic geometry at the site, whether or not sediment load was increased or decreased, and on the bank conditions. Also, the reduction in mean velocity and transport capacity would be a function of site geometry. These relationships could be more accurately described at a site using the shear-shape relationship from Appendix V.

- Consider using fault tree analysis in developing the adaptive management-decision making process (Figure 32, page 173 in preliminary draft report of July, 1989 for this project).

- Consider using Severity Factor Analysis in the Stream Response modeling project to demonstrate changes in stream channel and fish

habitat characteristics as a percentage of the change in a reference flow. (Pages 186-204 of the project preliminary draft report of July, 1989).

- **Keep up your good, dedicated work!**